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TECHNICAL NOTE 3531

PILOT'S LOSS OF ORIENTATION IN INVERTED SPINS

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Washington
October 1955

AFMDC

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SUMMARY

The pilot's loss of orientation during spins, especially during unintentional inverted spins, is a rising psychological problem and has apparently led to a number of accidents and near-accidents recently with both trainer and fighter airplanes during acrobatic maneuvers and after recovery from erect spins. In this paper, the nature of inverted spins, the optimum control technique for recovery, and some of the apparent reasons for the pilot's loss of orientation are discussed.

It is pointed out that a pilot in an inverted spin should attempt to orient himself with respect to direction of turn by referring to the airplane rate-of-turn indicator in order to determine properly the direction of the yawing component of the total spin rotation. Then, optimum recovery from the inverted spin should be obtainable by use of the following control technique: The rudder should be rapidly reversed from full with this yawing rotation to full against it while the stick is held full forward and laterally neutral; shortly thereafter, the stick should be moved from full forward to full back while it is maintained laterally neutral.

A description is included of a spin-simulator rig which has recently been constructed at the Langley Laboratory for use in an attempt to understand better the problems confronting the pilot of a spinning airplane.

INTRODUCTION

In addition to the problem of providing effective controls for recovery from spins of modern airplanes, there is a rising psychological problem concerning the pilot's loss of orientation that may occur because of the nature of the spin and its attitude. Even though the controls of an airplane may be effective for termination of the spin, proper deflection of the controls may be extremely difficult because the pilot has lost his orientation. This loss of orientation may stem from the very oscillatory nature of the spin both during the time of entry and after the spin has developed, or it may occur as a result of a rapid

change in the attitude of the airplane during recovery, perhaps due to pitching or rolling velocities. These velocities may lead to inverted spins after recovery from the erect spin. Accentuating this problem is a number of accidents and near-accidents which have been reported for both trainer and fighter airplanes as a result of unintentional inverted spins.

Free-spinning-tunnel results (ref. 1 and unpublished data) and reported airplane experiences concerning inverted spins and recoveries therefrom have been reviewed, and the present paper has been prepared in an attempt to provide information regarding the general nature of inverted spins, optimum control technique for recovery, and some of the factors which apparently contribute to the pilot's loss of orientation. Included is a description of a spin-simulator rig which has been constructed for use in an attempt to understand better the problems confronting the pilot of a spinning airplane.

SYMBOLS

The body system of axes referred to briefly in this paper is illustrated in figure 1.

X,Y,Z	longitudinal, lateral, and normal body axes of airplane, respectively
r	yawing angular velocity about Z body axis, positive when airplane is yawing to the pilot's right
p	rolling angular velocity about X body axis, positive when airplane is rolling to the pilot's right

DISCUSSION

Free-Spinning-Tunnel Results

Recoveries obtained from inverted spins of models in the Langley free-spinning tunnels have generally been rapid. Therefore, only a relatively small amount of testing time has been devoted to inverted spins, compared with the efforts expended during the past 20 years by the National Advisory Committee for Aeronautics in the many problems associated with erect spins and satisfactory recoveries therefrom. The inverted-spin tests that have been made in the Langley free-spinning tunnels have been on models of specific military airplane designs.

As indicated in reference 1, and as has been borne out by additional tests since the publication of that paper, inverted spins obtained on free-spinning-tunnel models have usually been steep with rates of descent somewhat higher than for erect spins of the same models. In the normal control configuration for inverted spinning (stick full forward and laterally neutral, and one rudder pedal full forward), the angles of attack during fully developed inverted spins have ranged for most models tested from about -30° to about -45° , although flatter inverted spins (more negative angles of attack) have been obtained for some models having no horizontal tail. Some models have spun smoothly with small or moderate oscillations and some have oscillated appreciably during inverted spins. Generally, the retreating (inner) wing in the spin tilted down toward the earth a few degrees from horizontal. Rates of rotation in developed inverted spins have generally been of about the same order as for erect spins (roughly 0.20 to 0.35 revolution per second, full-scale value). During the tests, most recoveries have been attempted by rudder reversal to full against the spin, and a relatively small number of tests have been made in which recoveries were tried by rudder neutralization. The wind-tunnel results have indicated that, with ailerons neutral and the stick full forward longitudinally, reversing the rudder from full with the inverted spin to full against the spin caused rapid recovery, and for some cases, mere neutralization of the rudder was sufficient.

Airplane Experiences

When a pilot intentionally enters an inverted spin, he does so by stalling the airplane in an inverted attitude, holding the stick full forward (elevator full up with respect to the ground) and kicking one rudder pedal full forward. These control dispositions, as previously indicated, make up what is considered to be the normal control configuration for inverted spinning. As the intentional inverted spin develops, the pilot generally remains oriented sufficiently to provide proper control manipulation for recovery. On some airplanes, rapid recovery from inverted spins is achieved by neutralizing the rudder and firmly moving the control stick to longitudinally neutral or full back, while maintaining it laterally neutral. On other airplanes, it is necessary to reverse the rudder rapidly to full against the spin as well as move the stick back in order to achieve recovery. More rudder against the spin may be required to recover from a fully developed inverted spin than from an incipient inverted spin. Also, because of such factors as asymmetric design, inadvertent asymmetry in construction for a specific airplane, or engine gyroscopic moments, more rudder against the spin may be required to recover from an inverted spin in one direction than in the other direction.

Inasmuch as rudder reversal to full against the spin is required for recovery from inverted spins for some airplanes and for some models,

it appears that this manipulation should be considered as part of a general optimum control technique for recovery. The complete optimum control manipulation for recovery from inverted spins would be as follows: The rudder should be rapidly reversed from full with the spin to full against it while the stick is held full forward and laterally neutral; shortly thereafter (about one-half turn later for recovery from fully developed spins), the stick should be moved from full forward to full back while it is maintained laterally neutral. The stick and rudder should be moved toward neutral as the rotation ceases and the spin is stopped in order to control the airplane during the ensuing recovery dive and avoid entering another spin, either inverted or erect. One important reason for reversing the rudder before the stick is moved back in the inverted spin (elevator moved down with respect to the ground) is to minimize any shielding effect that the elevator may have on the rudder in the inverted-spin attitude, which could detract from the effectiveness of the rudder in opposing the spin rotation. This situation is similar to that for recovery from erect spins, for which it is likewise true that full rudder reversal should precede movement of the elevator down (ref. 2, and others). As a general rule, the ailerons should be maintained laterally neutral during inverted spins and recoveries therefrom, although it is possible that in extreme cases, where specifically found necessary through free-spinning-tunnel tests, ailerons may have to be deflected to obtain recovery. General effects of aileron deflection on inverted spins and recoveries for airplane designs of 10 to 15 years ago indicated that holding controls together (for example, stick right when right rudder pedal is forward) during the developed spin was generally beneficial to recoveries by rudder reversal, whereas holding controls crossed in the developed spin was adverse to recovery by rudder reversal (ref. 1). However, on some more recent designs having extreme distribution of mass along the fuselage, the effects of ailerons on recovery from inverted spins will likely be opposite to those just indicated.

In the recent accidents and near-accidents caused by unintentional inverted spins, some of the spins were entered after inadvertent stalls of trainer airplanes during level inverted flight and during acrobatic maneuvers such as loops, Immelman turns, and wing-overs. Others were entered after recovery from erect spins of new high-performance fighter airplanes in which the control-manipulation technique used for recovery included moving ailerons to full with the spin, and were a result of the rolling motion obtained from this technique. (Movement of ailerons with the erect spin has become an essential part of the technique for recovery from erect spins of some contemporary high-performance airplanes with the relative distribution of weight very heavy along the fuselage (ref.3).)

Apparently, when attempting to recover from an inverted spin, a pilot may lose his orientation with regard to the direction of the spin, and thus with respect to the direction in which the rudder should be

moved to get it against the yawing rotation of the spin. The resultant rotation of an airplane in a developed inverted spin is actually about an approximately vertical spin axis just as it is during a developed erect spin; but, whereas in an erect spin the rolling and yawing velocities are in the same sense (for example, r and p are positive in an erect spin yawing to the pilot's right), in an inverted spin the rolling and yawing velocities are in opposite senses (for example, r is positive and p is negative in an inverted spin yawing to the pilot's right). A pilot in an inverted spin, looking down at the ground, would perceive his direction of roll and would note his correct yawing sense only if he could concentrate on the yawing panorama passing the nose or wing tips of the airplane.

Another possible reason for a pilot's loss of orientation is that during the incipient part of the spin the airplane may actually be alternately erect and inverted with respect to the ground. (The axis of spin has not yet become vertical.) Severe oscillations in some spins, during either the incipient or the fully developed stages, may also increase the difficulty in determining the direction of spin rotation and also in deciding whether the airplane is spinning erect, inverted, or alternately erect and inverted. Experienced pilots' comments have indicated that in a steep-attitude spin it is sometimes very difficult to decide, on the basis of eyesight and feel, whether the airplane is in an erect or an inverted attitude.

Inasmuch as recovery from either an inverted or an erect spin requires rudder reversal to oppose the yawing rotation, it appears that the best way for a pilot in a confusing spin to orient himself regarding the direction of rotation and to assure proper direction of rudder throw to oppose the yawing, whether the spin actually is inverted or erect with respect to the ground, is to refer to his rate-of-turn indicator and then rapidly reverse the rudder from full with the turning (yawing direction) indicated by this instrument to full against the turning. Even if there are large oscillations in the developed spin, a turn indicator that is functioning properly should indicate the true direction of the overall yawing motion during most or all of the time the spin is occurring. Also, if recovery is to be attempted during the incipient phase of either an erect or an inverted spin, even though in either type the airplane may be alternately erect and inverted with respect to the ground, the yawing rotation about the nonvertical incipient spin axis should be in one direction only and, therefore, should be indicated correctly on the turn indicator.

An alternate way of determining the direction of yawing is to look either along the X body axis directly past the nose or along the Y body axis past the wing tips to determine the direction in which the panorama is moving in the XY body plane. In this technique, it is necessary to disregard the rolling component of the airplane and its effect on the passing panorama.

If a pilot knows that he is definitely in an inverted spin, another alternate way of determining the direction of rudder throw for recovery from the inverted spin is to use deliberately the ground-rolling panorama for a reference but to use it in the correct manner for recovery from the inverted spin. In this technique, for example, the pilot would push left rudder pedal full forward in order to get it against the spin when he finds that he is in an inverted spin rolling to his left (yawing to his right).

Some additional factors can be mentioned at this time, although it is realized that many of these points are generally known. An important factor is the ability of the pilot in an inverted spin to reach and move the controls readily in any required manner. Also, having sufficient altitude during acrobatic maneuvers which may lead to inadvertent spins is necessary to insure that the pilot has time to orient himself regarding the spin and the recovery procedure. It would be prudent to test intentionally the inverted-stall behavior and possibly the entry into the inverted spin to some extent before doing acrobatic maneuvers which may lead to an unintentional inverted spin with any one particular airplane. Little is known as to the effect of applying power on recoveries from either erect or inverted spins, but a brief analysis using the equations of motion for a spinning airplane indicates that application of power may in some cases be adverse to recovery. Therefore, the application of power should not be depended on as a recovery technique, but rather power should be throttled down and proper control manipulation applied. If an airplane carries a drag parachute and an emergency occurs because of inability to recover from an inverted spin, it would seem desirable to open the parachute, inasmuch as the incremental effect resulting from opening the parachute should be such as to oppose the spin rotation.

SPIN-SIMULATOR RIG

In order to investigate the problem of a pilot's loss of orientation during spins, particularly inverted spins, the Langley Laboratory of the National Advisory Committee for Aeronautics has constructed a spin-simulator rig in which research personnel and pilots can be strapped and be rotated in erect or inverted-spin attitudes. Provision is made for various locations of the seat forward or rearward of the center of rotation, simulated variations of angle of attack and of wing tilt from horizontal, and optional pitching from erect to inverted-spin attitudes during rotation. Photographs of this rig are shown in figure 2.

CONCLUDING REMARKS

Pilot's loss of orientation during spins, especially during unintentional inverted spins, is a rising psychological problem and has apparently led to a number of accidents and near-accidents recently involving both trainer and fighter airplanes during acrobatic maneuvers and after recovery from erect spins.

It has been pointed out that pilots in inverted spins should attempt to orient themselves with respect to direction of turn by referring to the airplane rate-of-turn indicator in order to determine properly the direction of the yawing component of the total spin rotation. Then, optimum recovery from the inverted spin should be obtainable by using the following control technique: The rudder should be reversed rapidly from full with the yawing rotation to full against it while the stick is held full forward and laterally neutral; shortly thereafter, the stick should be moved from full forward to full back while it is maintained laterally neutral.

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Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 13, 1955.

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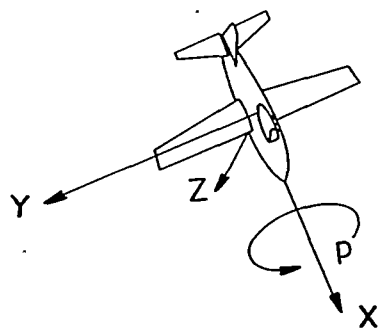
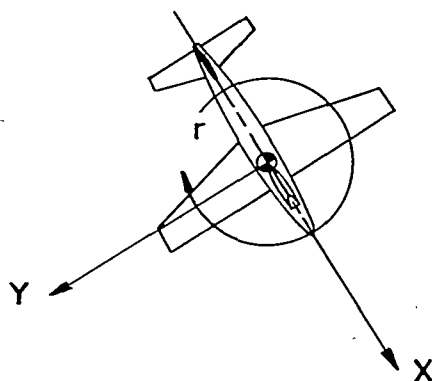
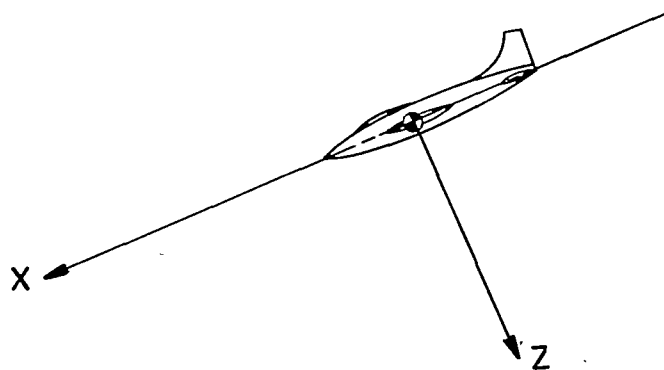
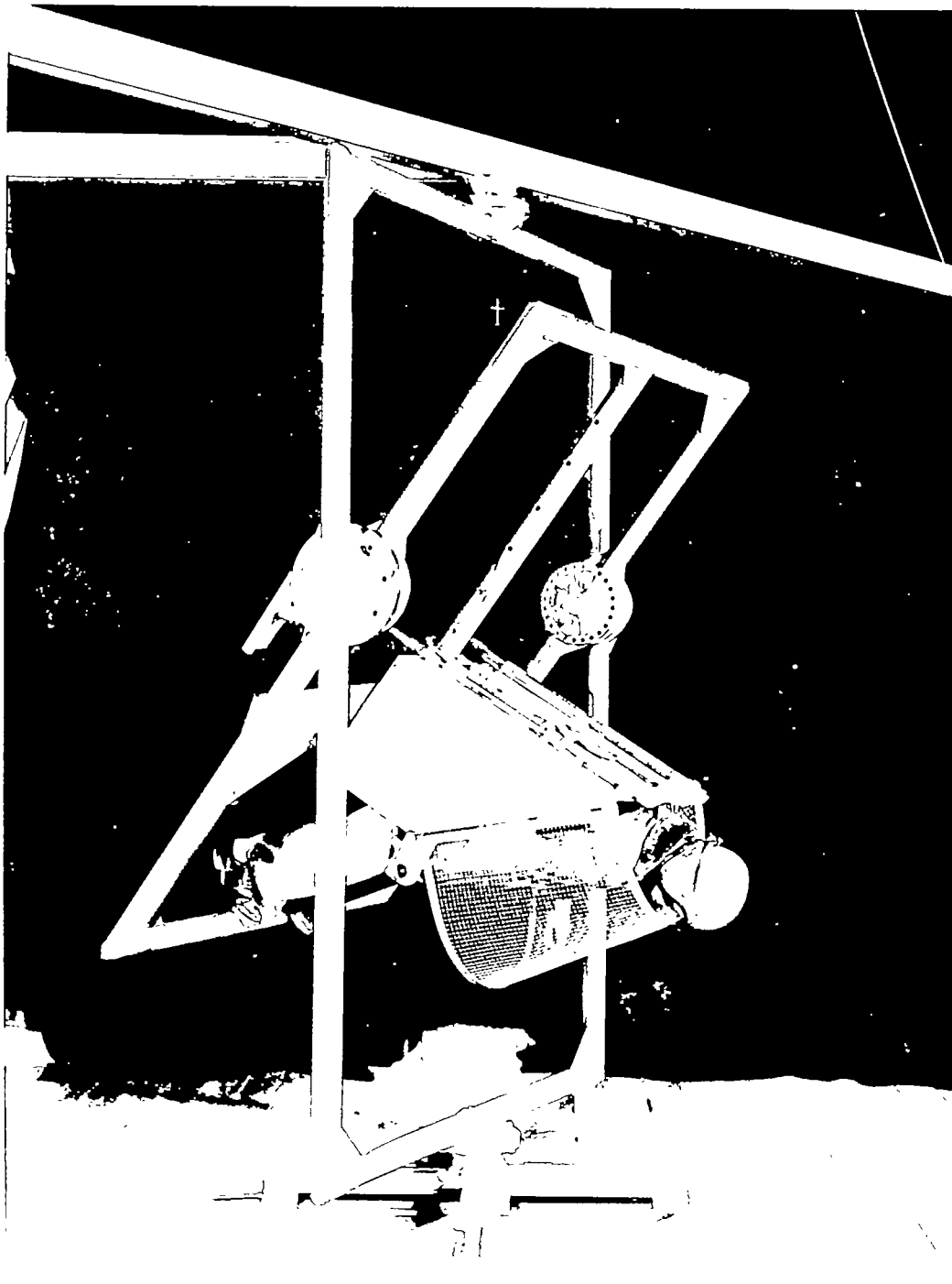


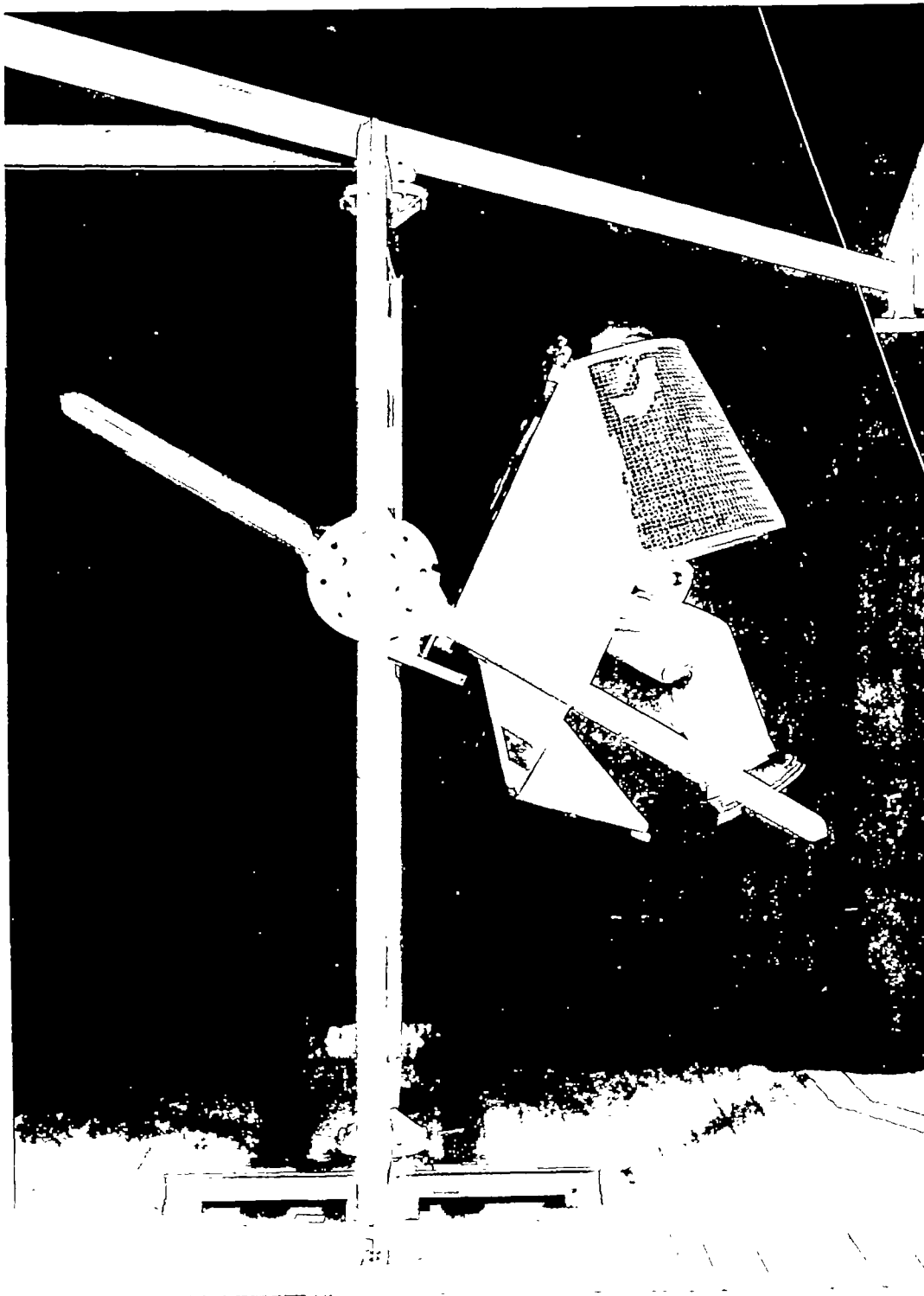
Figure 1.- Body system of axes and angular velocities. Arrows indicate positive directions.



(a) Inverted-spin attitude.

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Figure 2.- Spin-simulator rig and subject. Spin rotation is applied about vertical axis (imaginary) through upper and lower center supports.



(b) Erect-spin attitude.

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Figure 2.- Concluded.